

Development of a Toroidal Intersecting Vane Machine Air Management System for Automotive Fuel Cell Systems

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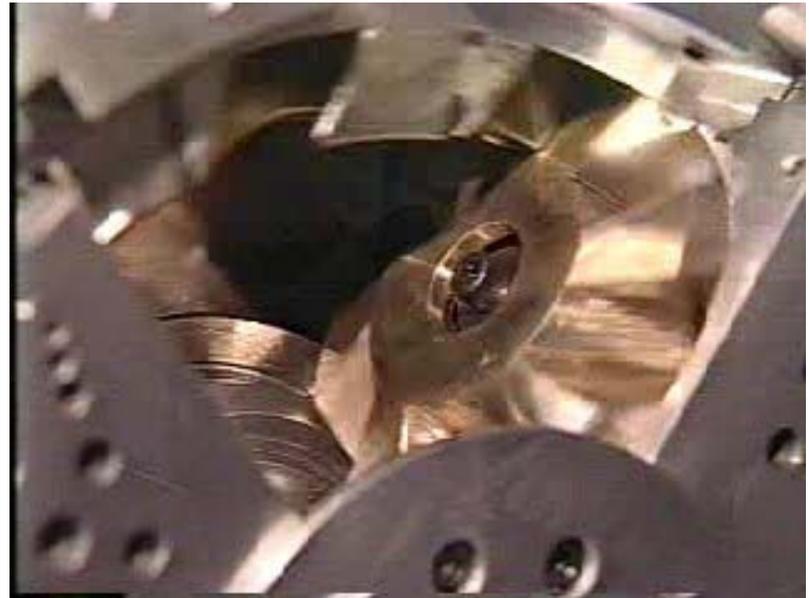
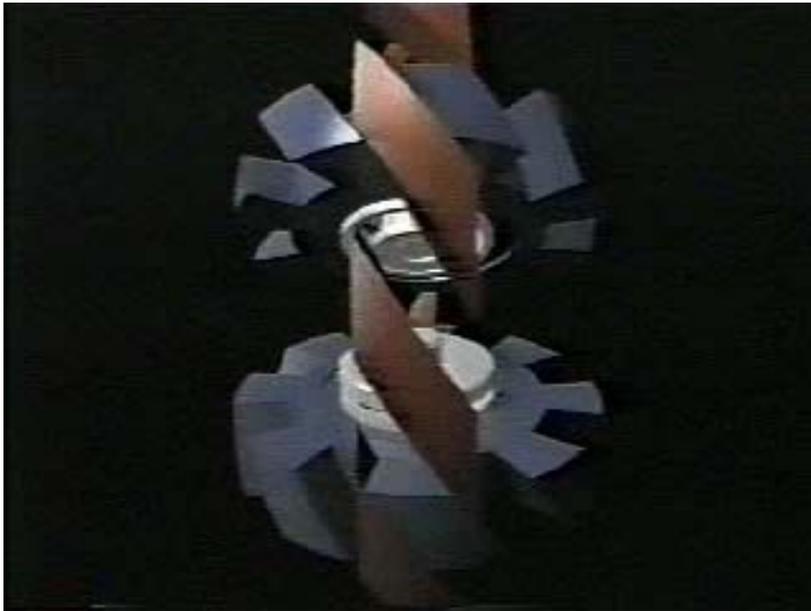
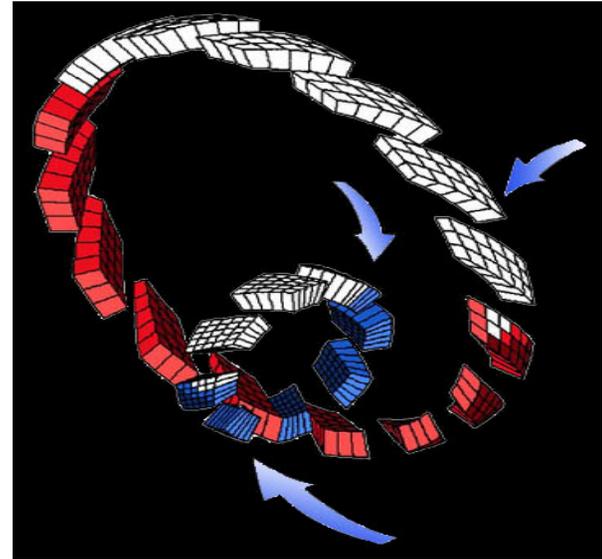
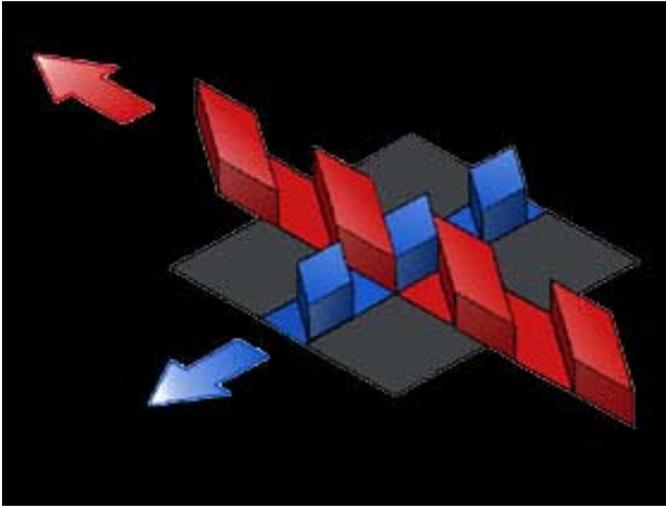
The focus of this program is to develop the innovative TIVM concept into working compressor/expander/motor hardware that satisfies the FreedomCAR Guidelines – and is easily adaptable to individual car system requirements – and to measure the TIVM air management system performance

Relevance and Objective of The TIVM Compressor/Expander/Motor Development Project

The Objective of Mechanology's TIVM CEM Development and Demonstration project is to overcome the following Transportation Systems Technical Barrier identified in the Draft Fuel Cell R&D Plan:

“Compressors/Expanders. Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. To validate functionality in laboratory testing, current systems often use off-the-shelf compressors that are not specifically designed for fuel cell applications resulting in systems that are heavy, costly, and inefficient. Automotive-type compressors/expanders that meet the FreedomCAR program technical guidelines need to be engineered and integrated with the fuel cell and fuel processor so that the overall system meets packaging, cost, and performance requirements. “

The Toroidal Intersecting Vane Machine Concept



Toroidal Intersecting Vane Machine Characteristics

Positive Displacement

- Compressor/Expander
- Compressor/Compressor
- Blower

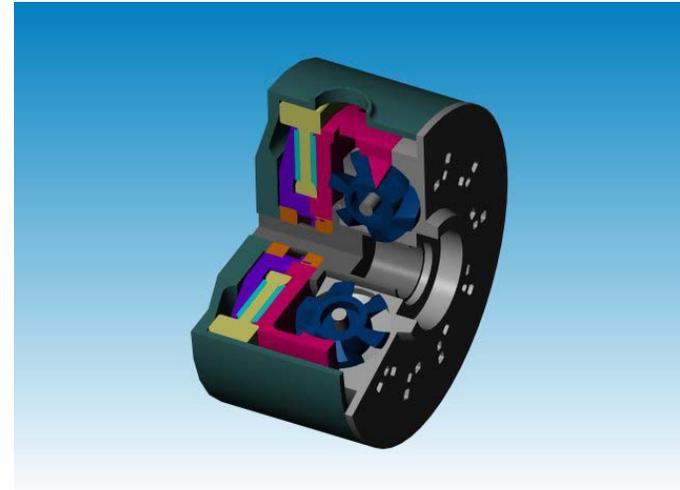
High Flow

High or Low Pressure

Small Volume

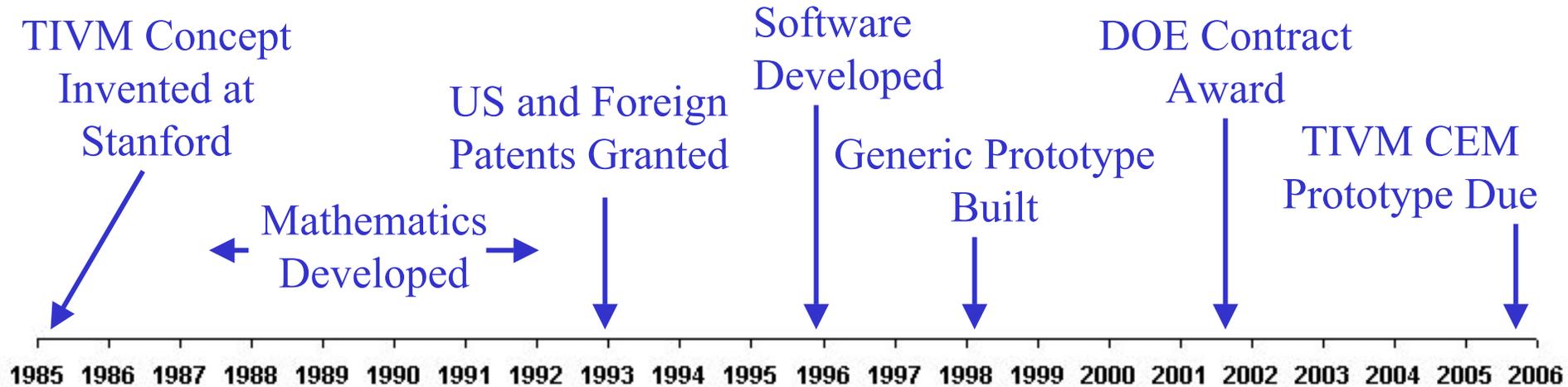
Low Production Cost

Many Spin-off Products

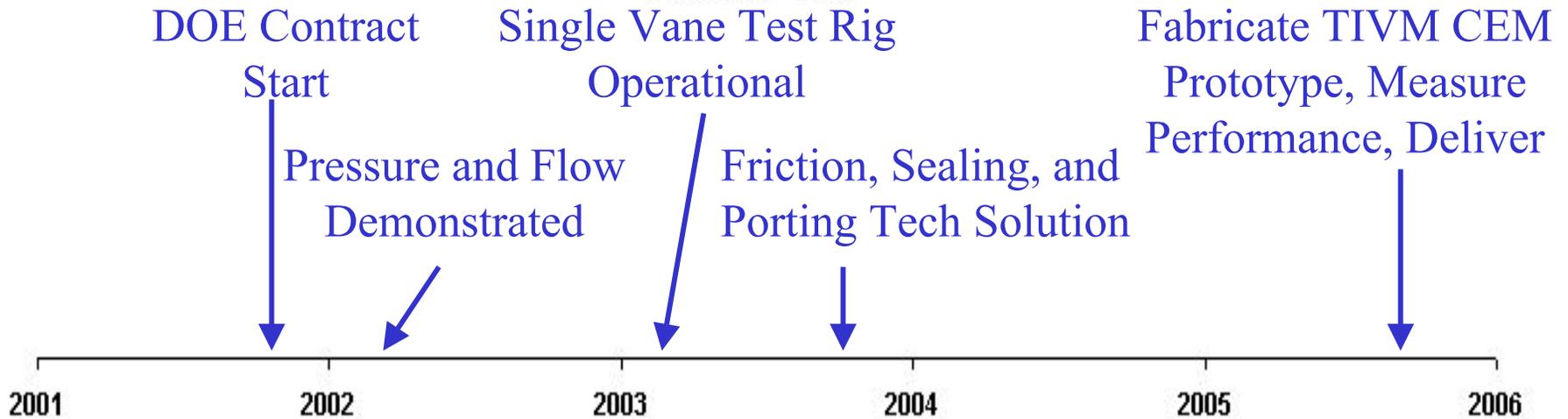


TIVM Attributes Provide Efficient Operation as an Integral Compressor/Expander for Automotive Fuel Cell Applications With Very Good Performance at High Turndown Ratios

TIVM Development Timeline

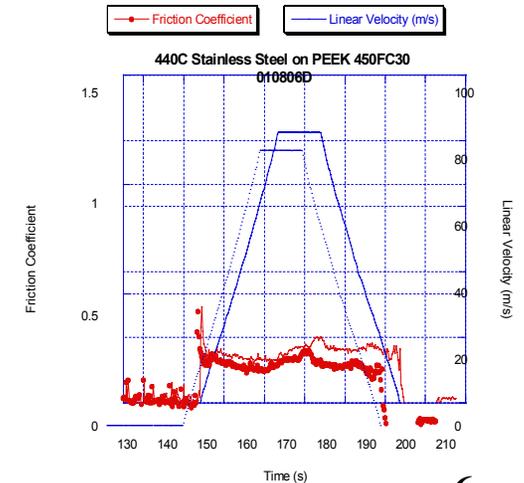
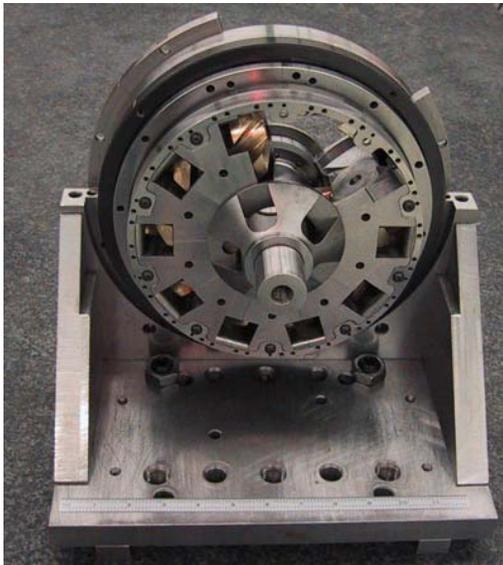
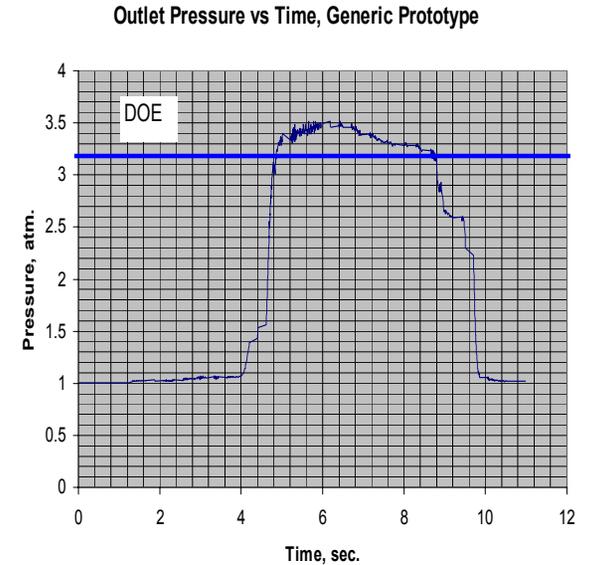
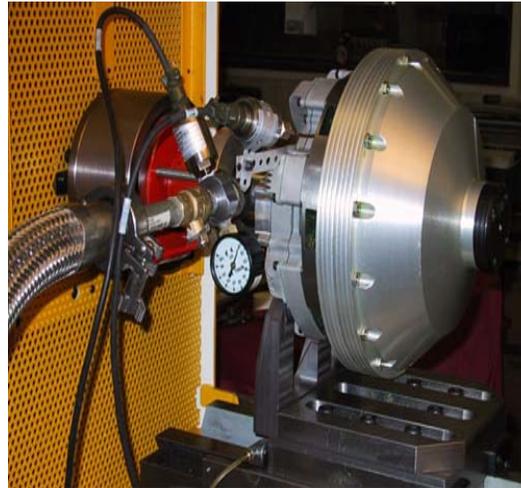
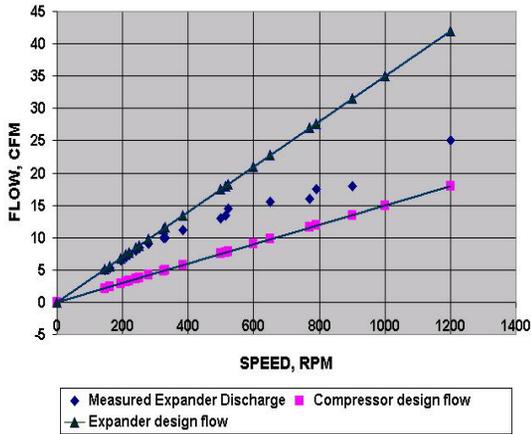


Calendar Year



Calendar Year

The Basic Viability of the TIVM Has Been Proven Through Hardware and Tests



Requirements Compliance Matrix for TIVM Compressor/Expander

| <u>Requirement</u> | <u>Value</u> | <u>Comment</u> | <u>TIVM Status</u> |
|--------------------|-----------------------------------|---|-----------------------------------|
| Flow | 76 g/s (135 cfm) For 50 kWe | Flow consistent with design flow demonstrated with temporary seals - as expected for positive displacement device | Capability Demonstrated |
| Pressure | 3.2 atm | 3.5 atm pressure demonstrated with temporary seals - as expected for positive displacement device | Capability Demonstrated |
| Power | 5.0 kW | Key remaining performance issue – requires low friction effective seals | 6 kW - Remains to be Demonstrated |
| Size | 8-11 liters | Acceptable to car makers and OEMs (Compressor, expander, and motor) | 8 L – Acceptable (2005) |
| Weight | 8-11 kg | Acceptable to car makers and OEMs | 16 kg – Acceptable (2005) |
| Noise | <70 db | Use of polymer parts and compliant seals will mitigate | To Be Demonstrated |
| Cost | \$400 | Cost estimates based on vendor quotes Give several \$100's in high volume | Expected to be acceptable |

Three Key Performance Issues Needed to Satisfy the Power Requirement

- Seals to limit air leakage without adding excessive friction
- Confirmation of coefficient of friction for meshing vane interface – including high humidity environment
- Porting to assure low pressure drop, and power loss, across the compressor and expander inlet and discharge paths

These are not unusual engineering tasks that require inventions or new materials. Solid, disciplined engineering development will provide the required solutions

Requirements for Vane Seals

(For 6 kW Shaft Power at 100% Power and Flow)

Limit air leakage from compressor and expander to $< 5\%$

- leakage rate < 0.38 g/s for full power and flow

- leakage rate < 0.076 g/s for 20% power and flow

Friction < 1.5 lb drag per rotor

Accommodate dimensional changes from wear, thermal expansion, fabrication tolerances, tolerance stack up. Requires compliance of $\sim 15 \times 10^{-3}$ inches

Manufacturable in large volume

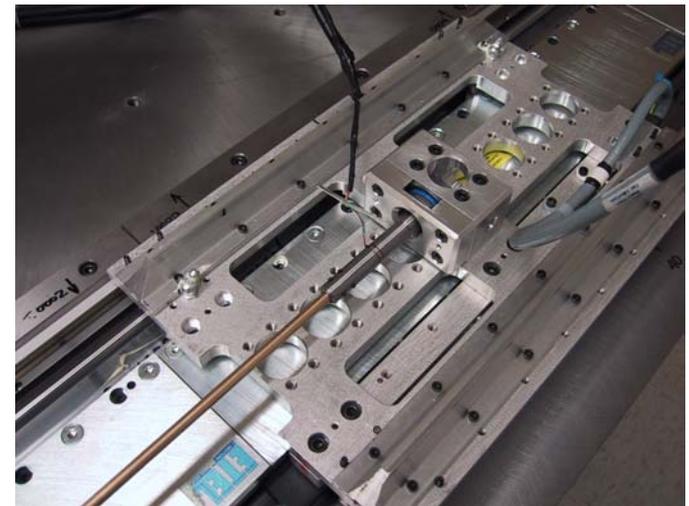
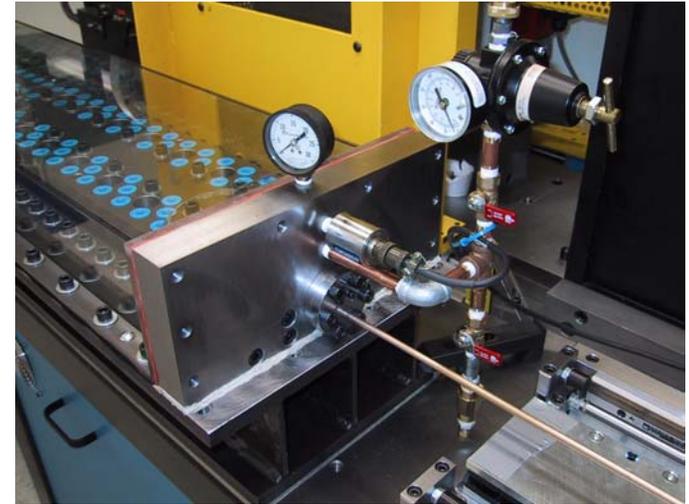
Cost effective

Single Vane Test Machine Features

- Designed for Development of Vane Seals
- Preserves Dimensional Scale of 50 kW TIVM / CE
- Leverages Existing Test Stand Hardware and Instrumentation
- Fast Turn Around Time for Test Specimens
- Static Sealing
- Dynamic Sealing (to 15 m/s vane velocity)
- Gas Pressure and Temperature (4 kHz)
- Seal Friction via Load Cell
- Linear Servo Motor

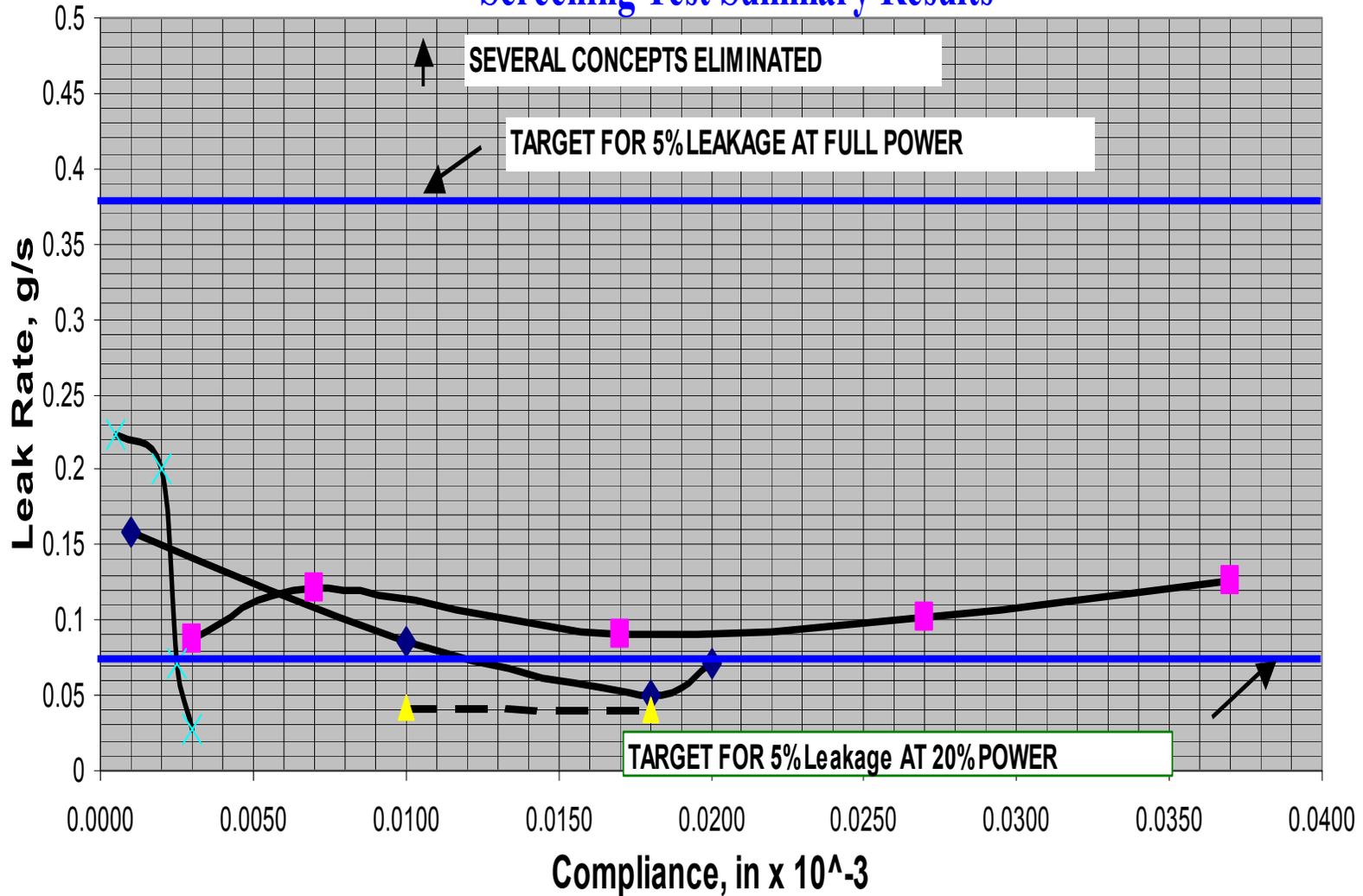
Position feedback (5 micron)

Velocity control (0 to 15 m/s)



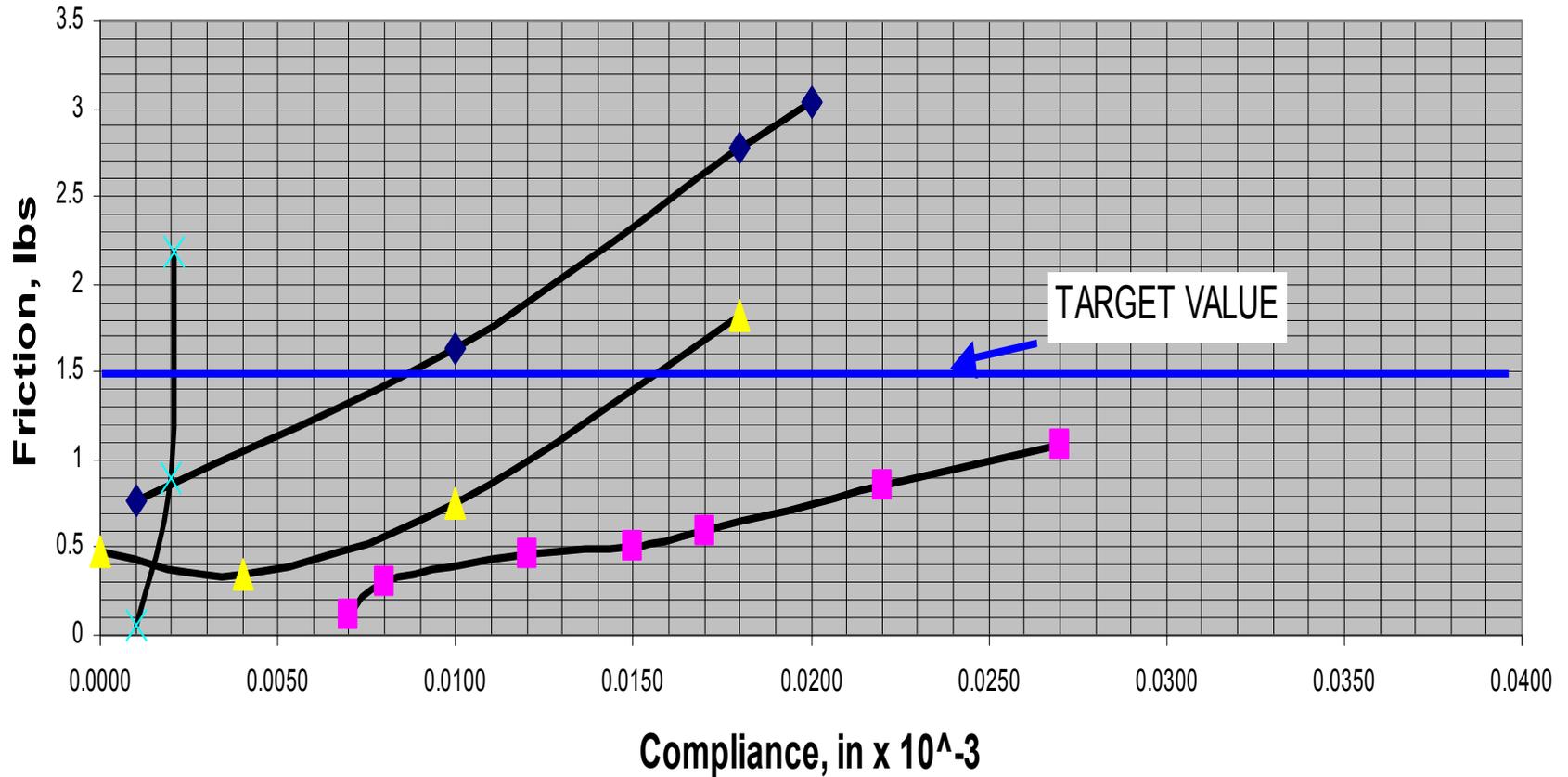
Leakage Rate vs Compliance For Several Seal Options

Screening Test Summary Results



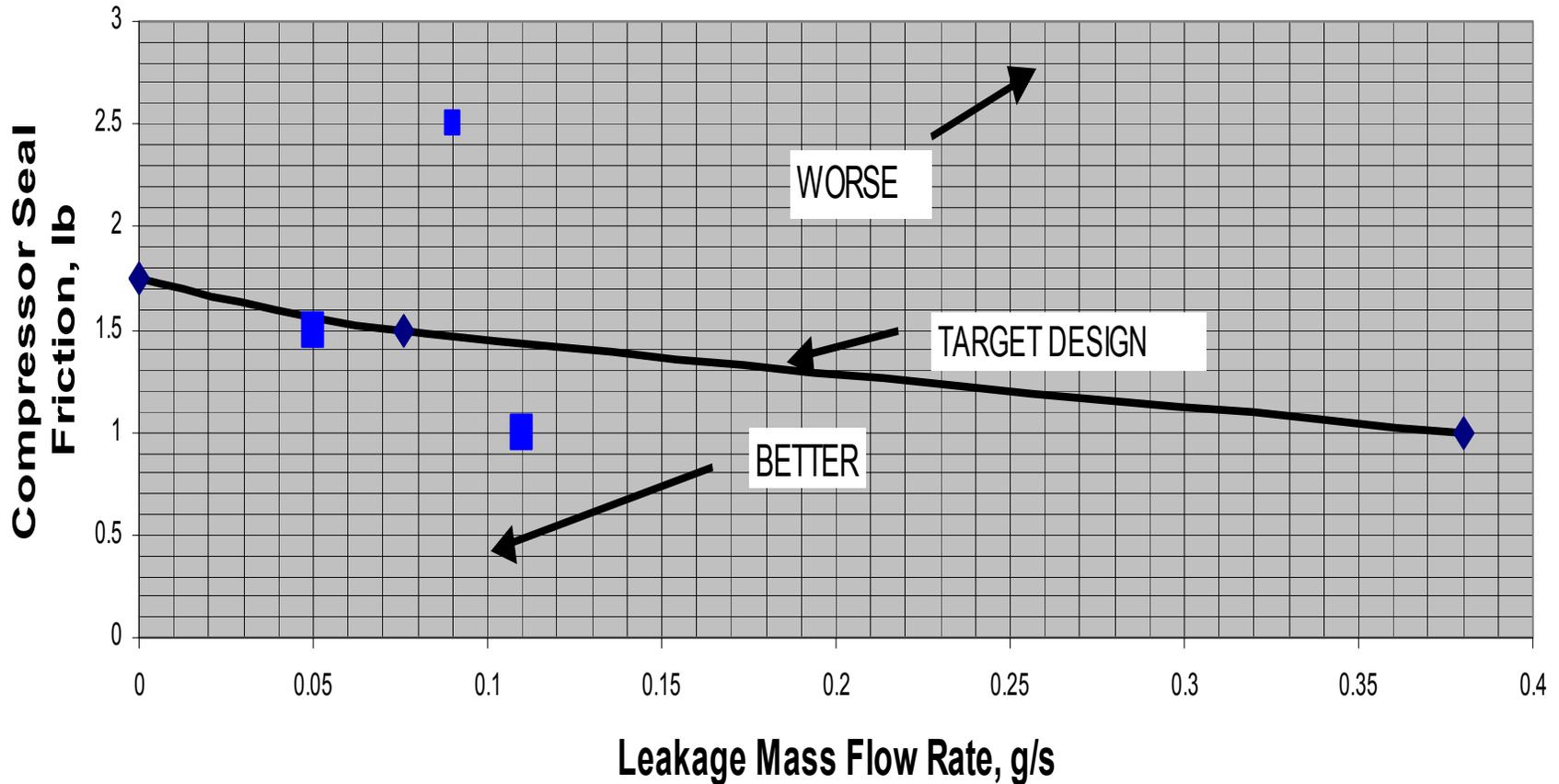
Two Seal Concepts Meet Full Power Requirements

Friction vs Compliance for Candidate Seals



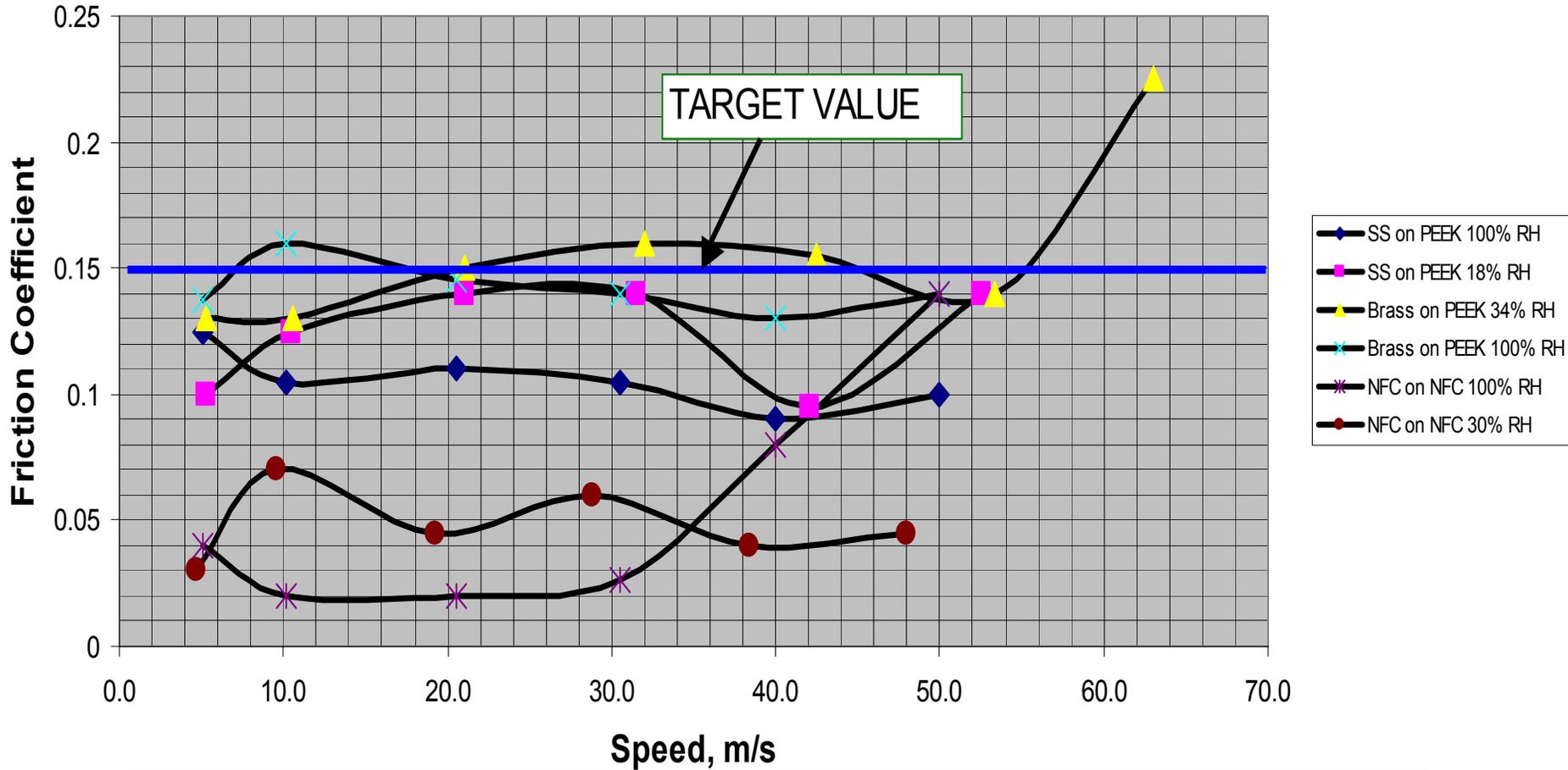
Two Seal Design Concepts Meet Friction Requirement

Leakage vs Friction Tradeoff for 6 kW Shaft Power



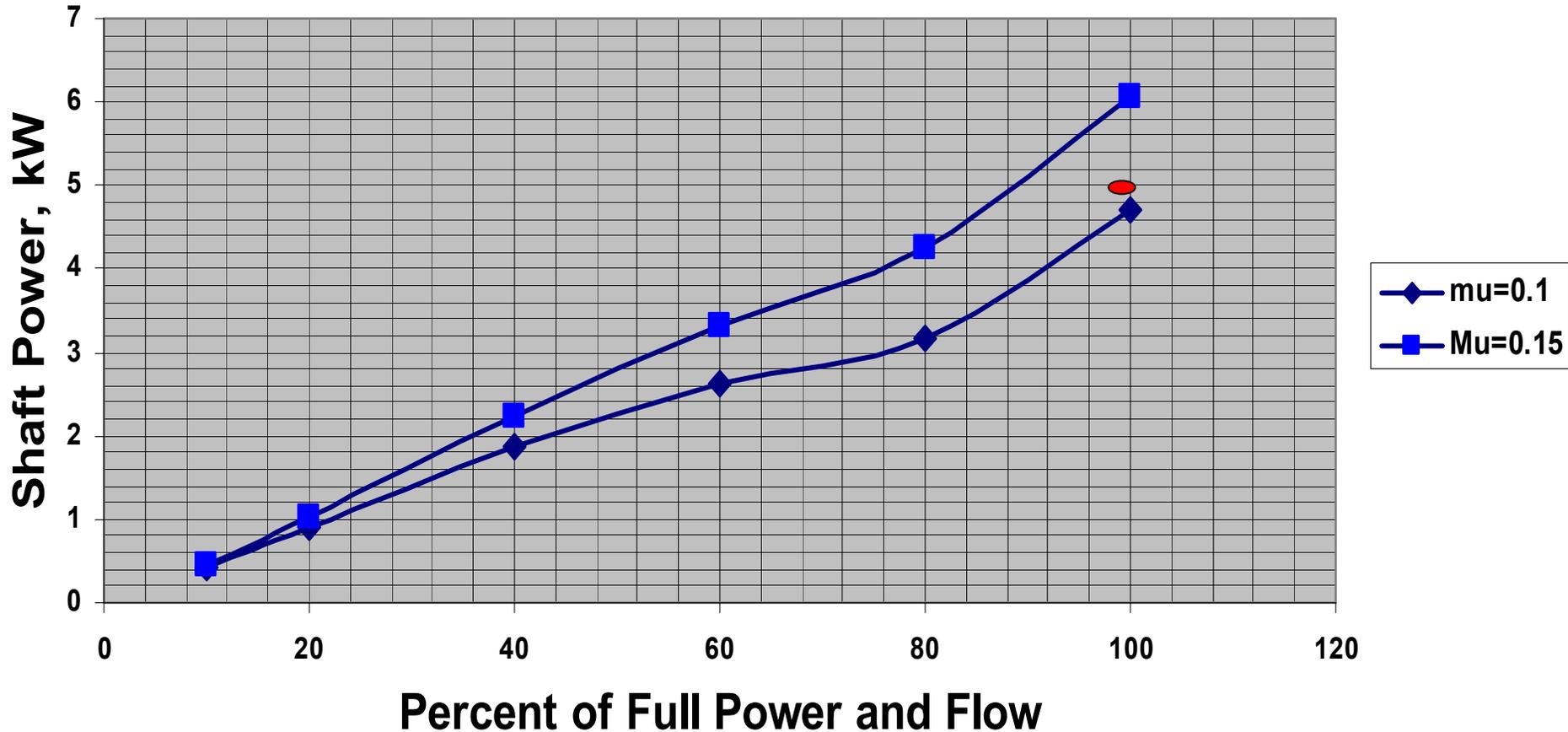
Two Seal Concepts Meet Leakage and Friction Requirements for 6 kW – Further Optimization Possible

Friction Coefficient vs Speed, Most Recent ANL Data



Vane to vane coefficient of friction of <0.15 is achievable

Shaft Power vs % Power and Flow, DOE Guidelines, Seal "B"
Characteristics and 3.2 atm Pressure



Parasitic power load of <6 kW appears to be achievable

Future Plans

Complete seal measurements for combined leakage and friction – confirm satisfactory performance of at least one design – August 2003

Perform porting feature measurements to confirm satisfactory performance – August 2003

Complete investigation of additional innovation with potential to reduce shaft power by $> 1\text{kW}$.

Build fully operational prototype with selected seals and ports – measure integral performance

With accelerated funding, August 2004

At planned funding rate, September 2005

Integrate high efficiency motor – measure performance, deliver to Argonne National Laboratory for testing

With accelerated funding, September 2004

At planned funding rate, September 2005